
Computational Methods Development at Ames

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Aeronautical Information Technologies Division
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Outline of Talk

- CURRENT THRUSTS
BACKGROUND / APPROACH
- RECENT ACCOMPLISHMENTS
HIGHLIGHTS
- CURRENT FOCI
- FUTURE DIRECTIONS



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Current Thrusts

- **BACKGROUND**

- Decrease design cycle time ⇒ Rapid turn-around
- Increase design/process fidelity ⇒ High accuracy and low variation
(Accurate flow physics)
- Increase discipline integration ⇒ Increased range of options via IT

- **OBJECTIVE**

Develop advanced computational methods to provide appropriate fidelity computational analysis/design capability



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Current Thrusts

- **APPROACH**

- **Advanced computational methods**
 - Enhance / accelerate viscous flow simulation procedures
 - Develop hybrid/polyhedral-grid procedure for viscous flow
- **Methods for evaluation and design process**
 - Develop real time transonic flow simulation procedure for production wind tunnel
 - Develop intelligent data management technology (IT)
- **Validation of methods and flow physics study**



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Recent Accomplishments / Work In Progress

- ADVANCED METHODS FOR VISCOUS FLOW SIMULATION

Enhance / accelerate viscous flow simulation procedures

- Accelerated convergence of OVERFLOW
- Developed MPI version of OVERFLOW
- Study/develop convergence acceleration methods

Develop hybrid/polyhedral-grid procedure for viscous flow

- Hybrid-Cartesian grid method in progress
- High-order polyhedral grid flux calculation formulated

Develop steady/unsteady incompressible solver with adaptive control



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Recent Accomplishments / Work In Progress

- METHODS FOR EVALUATION AND DESIGN PROCESS

Develop real time transonic flow simulation procedure for production wind tunnel

- Developed Transonic Overset Potential Solver (TOPS)

Develop intelligent data management technology (IT)

- Data compression (feature extraction) method being developed using multiresolution algorithm



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Recent Accomplishments / Work In Progress

- VALIDATION OF METHODS AND FLOW PHYSICS STUDY
 - Wingtip and wake vortex study
 - Unsteady incompressible N-S solver and adaptive control
 - Aeroacoustic applications :
 - Flap edge noise and acoustic modeling
 - DNS/LES for jet aeroacoustics



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Computational Methods Development

TECHNICAL HIGHLIGHTS



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Acceleration of Viscous Flow Simulation

- FUTURE VISION / PAYOFFS / BARRIERS
 - Two orders of magnitude improvement in turn around time will enable RANS applications to viscous flow design problems
 - Improved process time will impact design cycle time
 - Existing Navier-Stokes solution procedures are not efficient enough for engineering applications.
- APPROACH
 - Turn-around time of current RANS solver can be reduced by advanced convergence acceleration algorithms combined with parallel implementation
 - Advanced methods will be developed to reduce CFD process time from CAD to solution
- TASKS
 - Enhancement of OVERFLOW : preconditioning & multigrid, MPI version
 - Development of Cartesian-based hybrid-grid method
 - Development of acceleration algorithms

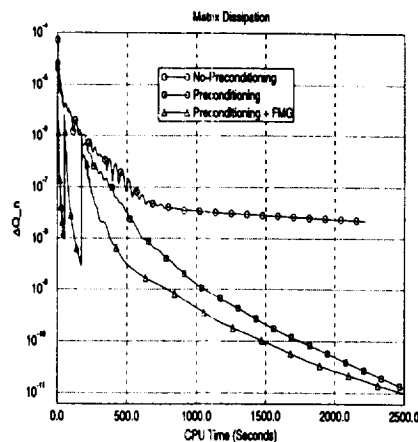


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Acceleration of Viscous Flow Simulations

Convergence Acceleration for N-S Computations

NACA4412 $M = 0.001$ $\alpha = 0$ $Re = 1.5$ Million



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Convergence Acceleration of OVERFLOW

DESCRIPTION

Convergence to steady state of the compressible Navier-Stokes code, OVERFLOW, has been accelerated with multigrid and also with low-Mach number preconditioning.

ACCOMPLISHMENTS

A multigrid algorithm has been added to OVERFLOW. It handles "Chimera" geometries.

A low Mach number preconditioning option has been added for cases with low free stream Mach numbers (less than 0.2).

SIGNIFICANCE

Convergence to steady state has been accelerated by a factor of up to 6 for NACA 4412 at $M=0.2$ and $Re=1.5$ million case.

WORK IN PROGRESS / FUTURE

Robustness of the algorithms in multi-zone geometries is being enhanced.

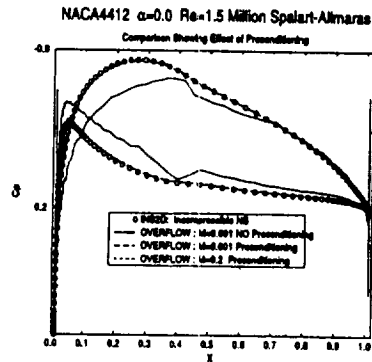
POC: D. Jespersen, 4-6742, jespersen@nas.nasa.gov

T. Pulliam, 4-6417, pulliam@nas.nasa.gov

Acceleration of Viscous Flow Simulations

Effect of Low Mach Number Preconditioning in OVERFLOW

NACA4412 $\alpha=0.0$ $Re=1.5 \times 10^6$ Spalart-Allmaras



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● OVERFLOW / MPI

DESCRIPTION

To reduce turn-around time for obtaining Navier-Stokes Solutions, a parallel version of OVERFLOW has been developed that exploits parallelism at all levels.

ACCOMPLISHMENTS

An MPI version of OVERFLOW has been successfully run on workstations, SP2, T3E, Power Challenge, Origin2000 and Onyx2.

SIGNIFICANCE

Distributed linear solver is at 60-80% of ideal efficiency.

Load balancing allows splitting of large zones across processors and clustering of multiple small zones onto one processor.

WORK IN PROGRESS / FUTURE

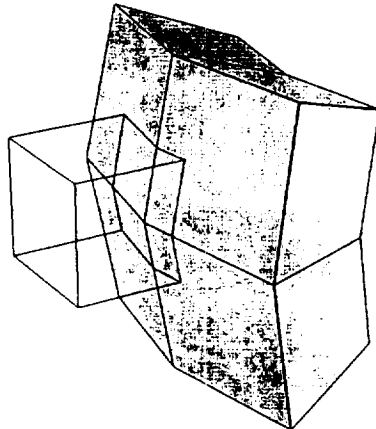
The code will be integrated into the standard OVERFLOW and will be a part of the OVERFLOW distribution.

POC: D. Jespersen, 4-6742, jespersen@nas.nasa.gov

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Acceleration of Viscous Flow Simulations

Illustration of Polyhedral Interface Cells



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● Finite Volume Methods for Arbitrary Polyhedral Grids

DESCRIPTION

One key element in developing a hybrid-grid method is how to handle irregular polyhedral cells at interface boundaries. The objective of the current effort is to develop theoretical foundation to achieve very high order accurate solutions for general polyhedral grids.

ACCOMPLISHMENTS

High order flow variables and fluxes for arbitrary polyhedral and polygonal grids have been formulated based on exact integration of polynomials and quadrature approximations.

SIGNIFICANCE

Processing time to generate grids for flows past complex geometries can be significantly reduced by relaxing grid generation requirements, i.e. structured viscous grids on Cartesian outer grids.

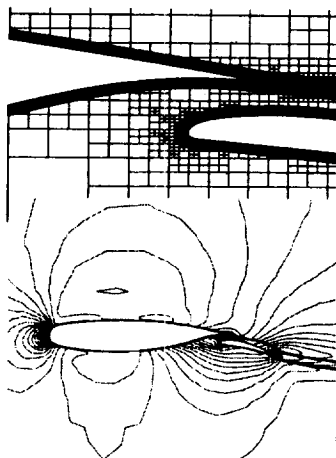
FUTURE PLAN

Formulas will be incorporated into existing RANS code to generate polyhedral grid Navier Stokes capability.

POC: Y. Liu / M. Vinokur, 4-6667, liu@nas.nasa.gov

Acceleration of Viscous Flow Simulations

Structured-Cartesian Hybrid Grid Solution
NLR 7301, $M=0.2$, $Re=10^6$, $\alpha=0$



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● Hybrid-Grid Method for CAD to RANS Solutions

DESCRIPTION

For 3-D applications: Multiblock grid generation procedure is expensive; Overset grid approach suffers from interpolation inaccuracies; Existing unstructured grid method using triangles needs improvement for viscous flows.

The objective is to develop a hybrid grid method using locally nonoverlapping structured grids on the Cartesian grid background. This requires development of advanced methods for the interface boundaries filled with irregular polygons.

ACCOMPLISHED

High order fluxes for irregular polygons have been formulated. Quadratic reconstruction formula has been implemented in 2-D with Roe splitting and an implicit GMRES method.

SIGNIFICANCE

The present approach will simplify the grid generation process substantially.

WORK IN PROGRESS / FUTURE

High order method for general polyhedral cells will be implemented in 3-D.

POC:M.Delanaye, 4-5176, delanaye@nas.nasa.gov

Real Time Transonic Flow Simulation in Wind Tunnel

● FUTURE VISION / PAYOFFS / BARRIERS

- Cost / solution time determines the hierarchy of method selected
- Quick solutions can be generated in real time to provide critical information for early design/test decision
- RANS approach is impractical for real time applications during production wind tunnel tests

● APPROACH

- For real time applications, implement fast potential solver (TOPS) using the same grid topology used for OVERFLOW
- Develop/implement boundary layer correction
- Develop zonal methods through IT based decision process

● TASKS

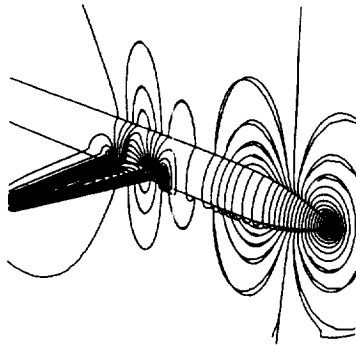
- Transonic overset-based potential solver (TOPS)
Develop TOPS to include wind tunnel wall and support
Add boundary layer correction into TOPS
Determine range of applicability and variations



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Real Time Flow Simulations

Mach contours: three-zone RAE Wing A with B2 fuselage at $M=0.9$, $\alpha=4^\circ$



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● Transonic Overset Potential Solver (TOPS)

DESCRIPTION

Potential/Boundary-Layer approach for transonic cruise analysis and design can be up to 100 times faster than Navier-Stokes. Full potential capability using existing Chimera zonal grid approach will be valuable for real time application of CFD for wind tunnel tests.

ACCOMPLISHMENTS

Transonic 3-D two-zone wing solver has been completed.

Transonic 3-D three-zone wing/body solver has been completed.

New donor cell search algorithm developed which is up to $\times 100$ faster than existing algorithm.

SIGNIFICANCE

Results to date demonstrate viability of full potential Chimera approach, which is compatible with existing OVERFLOW environment.

WORK IN PROGRESS / FUTURE

Complex geometry applications are in progress. The method will be extended to viscous flow, W/T wall interference study and design optimization.

POC: T. Holst, 4-6032, tholst@mail.arc.nasa.gov

Data Management and Feature Extraction Method

● FUTURE VISION / PAYOFFS / BARRIERS

- Intelligent information management is essential to IT based computational simulation methods development
- Method for data compression and reconstruction within specified accuracy can reduce storage requirement and transmission time significantly (i.e. at least an order of magnitude reduction)
- CFD data compression tool (code) is not available

● APPROACH

- Develop multiresolution algorithm to compress 3-D vector quantities and demonstrate the capability using CFD data such as wing tip vortex flow

● TASKS

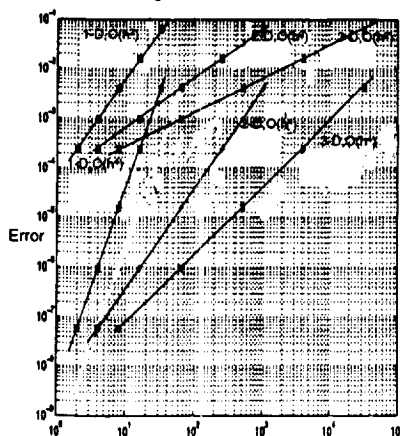
- Develop data compression and feature extraction algorithm / code



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Data Management and Feature Extraction Methods

Compression of Analytic Data Using Multiresolution Algorithm



Compression



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- **Multiresolution Algorithm for 3-D Data Compression**

DESCRIPTION

Numerical solution is, in general, only an approximation to the physical solution therefore for many purposes truncation of numerical data is acceptable. An efficient data compression algorithm for large 3-D data sets is desired for storage and transmission of data.

ACCOMPLISHMENTS

A prototype 3-D truncation compression algorithm has been programmed in Matlab and Fortran. This code is based on Harten's multiresolution algorithm with smooth basis functions.

SIGNIFICANCE

Since most numerical flow solutions are smooth almost everywhere, this algorithm should provide efficient CFD data compression.

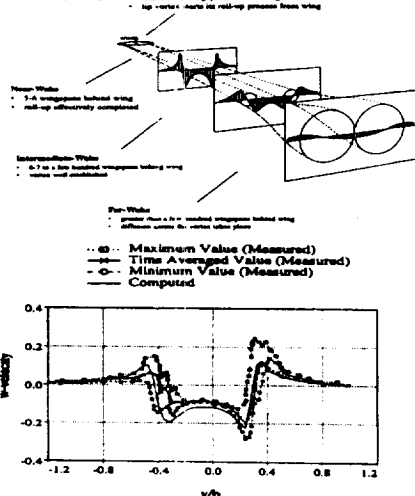
Truncation even with high accuracy (e.g. 99%) may allow significant compression thus reducing storage and transmission requirements

WORK IN PROGRESS / FUTURE

Will develop a 3-D CFD data compression code

CFD Application to Safety

Wake of a Lifting Wing



Wake of a B-747 scale model: velocity profile at $x/c=162$

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● Characterization of Wake Vortex

DESCRIPTION

To develop predictive capability for aircraft wake, it is important to characterize the initial tip vortex formation/roll-up process and the near wake behavior. The objective of the present study is to assess current capabilities and define requirements for numerical simulations.

ACCOMPLISHED

Tip vortex formation and roll-up process have been studied in detail addressing the roles of numerics and turbulence model in prediction.

Applicability of a simplified Navier-Stokes solver using velocity-vorticity formulation was investigated for wake modeling. This model was compared with 0.03 scale model test of B747 (80x120 data by Rossow et al.).

SIGNIFICANCE

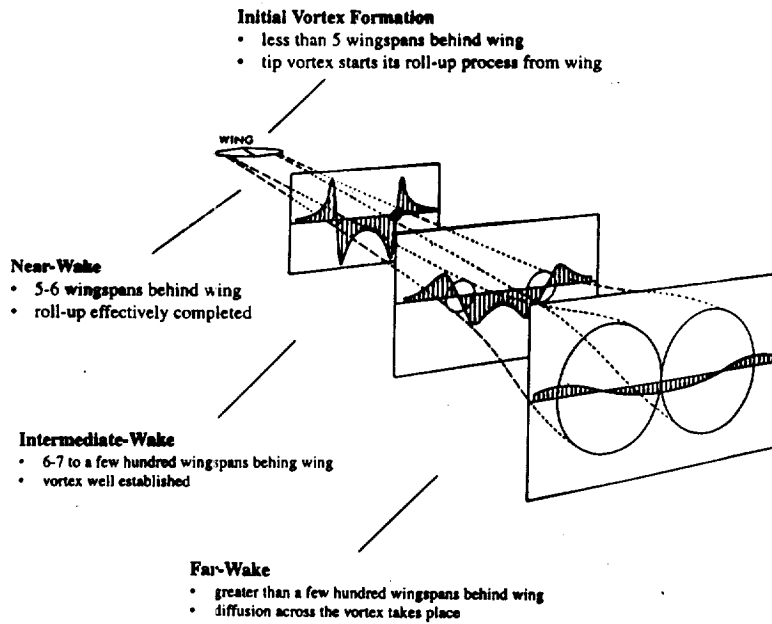
The current work is an attempt to develop a physics-based wake vortex prediction model.

WORK IN PROGRESS / FUTURE

Grid adaption methods are being investigated to reduce the grid density requirement.

POC: J. Dacles-Mariani, 4-5369, dacles@nas.nasa.gov

Wake of a Lifting Wing



COMPUTED RESULTS

Test Conditions for B-747 Modeled in the 80 x 120 ft Wind Tunnel*:

Freestream Velocity = 131 ft/sec

Dynamic Pressure = 20 lb/ft²

Distances = 81 and 162 ft

Data on Wake Generating Model

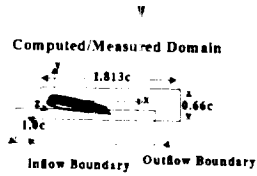
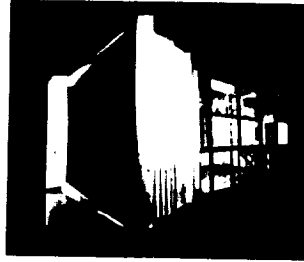
Parameter	B-747
Scale of Model	0.03
b (wingspan)	70.5 in.
c (wing chordlength)	10.1 in
Re	660,000
Aspect Ratio	6.96
S (wing planform area)	4.94 ft ²

*Rossow, et al. (1993)

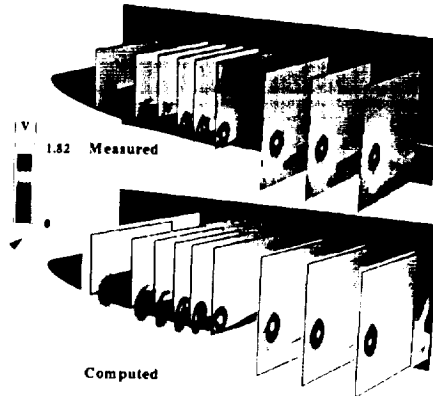
WINGTIP VORTEX VALIDATION STUDY

INS3D-UP CODE, NACA0012, $Re = 4.6e6$, $\alpha = 10^\circ$, GRID SIZE = $115 \times 157 \times 83$

32 in. x 48 in. FML Wind Tunnel



Velocity Magnitude Comparison between Exp. and Computation



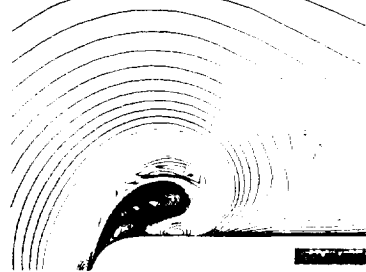
WINGTIP VORTEX STUDY

Turbulence Model/Grid Density Assessment

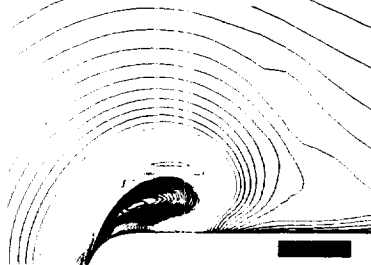
Experiment



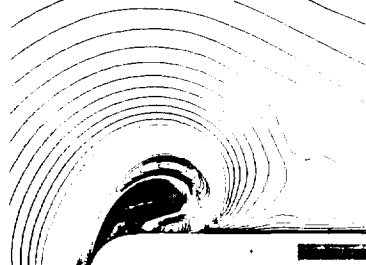
1.5 million grid points (SA model)



1.5 million grid points (BB model)

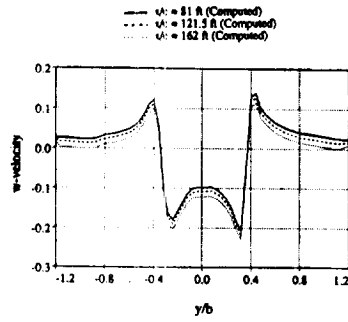


2.5 million grid points (SA model)

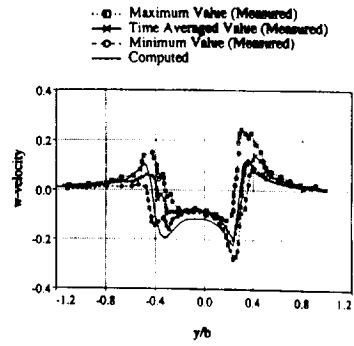


COMPUTED RESULTS

FULL NAVIER-STOKES FORMULATION

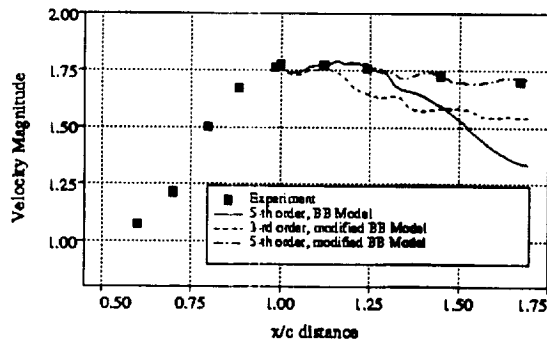


Computed w-velocity progression in the streamwise direction



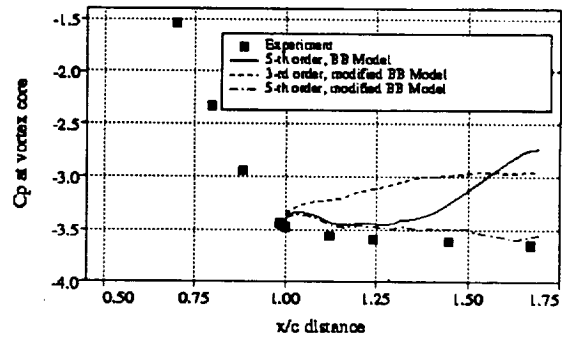
Comparison of the up- and downwash velocity profile with measured data at $x/c = 162$ ft

AXIAL PROGRESSION OF WINGTIP VORTEX IN NEAR-WAKE



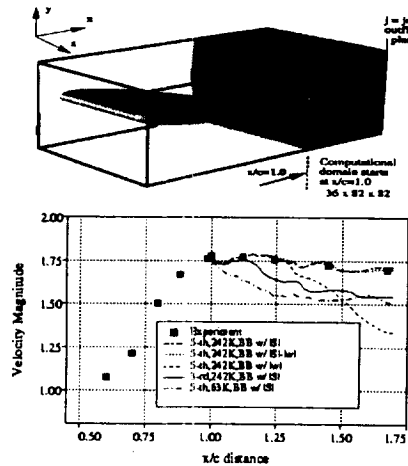
NACA 0012 WING
WITH ROUND TIP

$Re = 4.6$ Million
 $\alpha = 10^\circ$



Incompressible Navier-Stokes Methods

Axial progression of wingtip vortex in near-wake
NACA 0012 wing with round tip: $Re=4.6 \times 10^6$, $\alpha=10^\circ$



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- Fractional-Step Method for Time-Accurate Incompressible Navier-Stokes Computations

DESCRIPTION

Both artificial compressibility method and preconditioned compressible N-S methods require subiterations for time-accurate solutions of incompressible Navier-Stokes equations.

The objective is to develop an efficient unsteady incompressible method for 3-D applications using fractional step method.

ACCOMPLISHMENTS

Implicit Runge-Kutta scheme of order N and GMRES have been implemented.

Spalart-Allmaras as well as Baldwin-Barth model have been implemented.

Validation cases include Pulsatile flow through constricted channel and a wake vortex problem.

SIGNIFICANCE

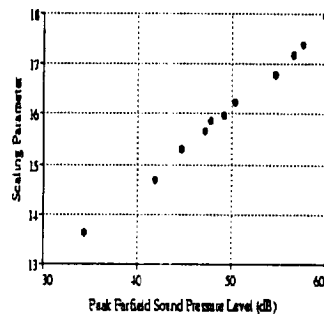
The CPU time requirement for unsteady calculations has been reduced by a factor of 3-5.

WORK IN PROGRESS / FUTURE

Robustness at high Reynolds number with highly stretched grid cases is being enhanced.

Exploratory Research - Noise Correlation

Far-Field Noise from A Family of Single Element NACA Wings



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- Correlation of Wingtip Noise with Mean Flow Parameters

DESCRIPTION

Correlations between steady, mean-flow parameters and radiated farfield noise were found for a single-element wing with a round tip.

APPROACH

Steady, incompressible RANS (INS3D-UP) calculations provided detailed flow information for the wing investigated. An experimental test performed at LaRC (Brooks and Marcolini, 1986) provided farfield noise measurements. The two investigations were combined to generate a correlation that held for combinations of aspect ratio, Reynolds number, and angle of attack.

SIGNIFICANCE

Correlations help understand what flow features produce farfield noise, suggest ways to reduce noise, and make possible an acoustic model that would use steady flow parameters.

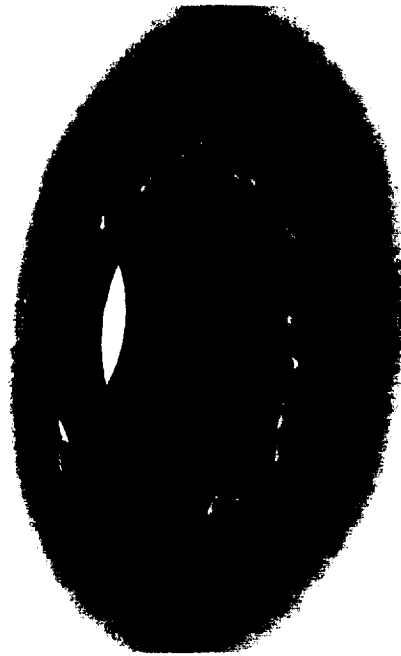
WORK IN PROGRESS / FUTURE

The same correlations are being applied to the flap side edge of a multi-element wing.

POC: D. Mathias, 4-0836, mathias@nas.nasa.gov

11 INCH SSME HPFTP IMPELLER

Pressure



Shrouded impeller

6 full blades

6 long partials

12 short partials

Impeller shaft speed : 6322 rpm

Impeller exit wheel speed :

3641 in/sec

Impeller exit diameter : 11 inches

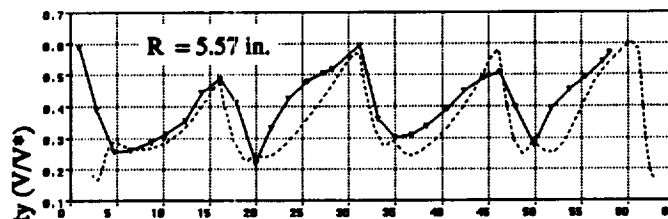
Reynold Number : 1.81×10^5

Reference length : 1 inch

Reference velocity : 284 in/sec

Fluid medium : water at 70 F

Hub surface colored by static pressure

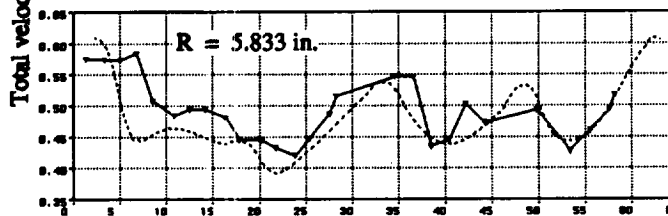


SSME-HPFTP Impeller

downstream of impeller

exit plane

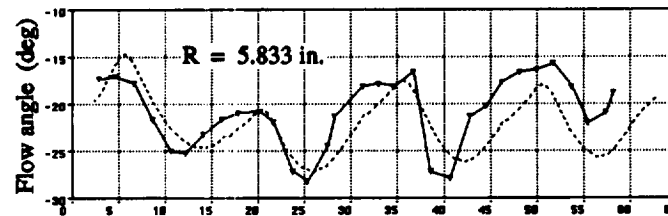
(51% of blade height)



Impeller exit radius :

5.5 in.

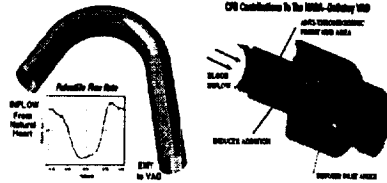
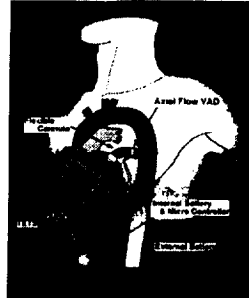
V^* : Impeller exit wheel speed (303.5 ft/sec)



Circumferential angle from suction side (deg)



Exploratory Research-CFD Application to Biofluid



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● CFD-Assisted Development of a Long Term Ventricular Assist Device (VAD)

DESCRIPTION

Short-term VAD (two-week pump) has been successfully developed with the aid of INS3D. For long term use, the device has to be controllable adjusting to the patients activity which requires full unsteady flow analysis.

The objective is to develop a long term VAD by implementing adaptive control in conjunction with unsteady flow simulations.

ACCOMPLISHMENTS

Developed unsteady flow simulation procedure which can be used for the entire configuration.

Pulsatile flow through various inlet cannula designs were compared.

SIGNIFICANCE

Development of the device could not have been possible without CFD capability.

WORK IN PROGRESS / FUTURE

Unsteady flow simulation for the entire geometry including an adaptive control model will be attempted.

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D. Kwak, 4-6743, dkwak@mail.arc.nasa.gov

Historical Examples

- MAJOR ACCOMPLISHMENTS

Ames has produced the original basic advances in CFD necessary for aeronautic applications and has helped extend CFD into many new and critical aerospace applications.

Following are only a few examples in critical CFD processes illustrating Ames contribution in the recent past:

Grid Generation advances and codes:

Developed elliptic, hyperbolic, unstructured point-insertion and local optimization, patched and overset (Chimera) domain decomposition grid procedures.

Resulting codes include

3D GRAPE, HYPGEN, DCF, SAGE, SURGRID, PRISIM, DELAUNAY



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Historical Examples

- MAJOR ACCOMPLISHMENTS (Cont'd)

CFD Algorithm advances:

Developed following algorithms and disseminated throughout the US:

MacCormack explicit algorithm

Beam-Warming approximate factorization algorithm

AF1/AF2 algorithm for small disturbance and potential flow

Pulliam-Chaussee diagonalized ADI algorithm

Steger-Warming flux-splitting algorithm

Pseudo compressibility algorithm for Incompressible Navier-Stokes equations

Linear-reconstruction unstructured scheme

Flow Solvers and codes:

Small-disturbance, potential and BL: Bailey-Ballhaus, LTRAN2, TAIR/
TWING, BL3D

Euler/Navier-Stokes: ARC2D/3D, TNS, PNS, TIGER, OVERFLOW, CNS

Incompressible: INS3D family of codes

Aero-elastic: ENSAERO

Rotorcraft: TURNS, OVERFLOW_Rtrcrt

Turbomachinery: ROTOR, STAGE



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Incompressible: INS3D family of codes

Aero-elastic: ENSAERO

Rotorcraft: TURNS, OVERFLOW_Rtrcrt

Turbomachinery: ROTOR, STAGE



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Historical Examples

- MAJOR APPLICATIONS

Aerospace:

- Coupled aerodynamic-structured prediction of flutter
- Full fighter aircraft performance predictions: transonic cruise (F-16), high alpha (F-18 with Dryden), STOVL (Harrier)
- Full rotorcraft performance prediction (e.g. V-22)
- Full simulation of the Space Shuttle stack performance (with JSC)
- "Tip-to-tail" hypersonic aircraft performance prediction
- Single- and multi-stage turbomachinery performance prediction
- Simulation/redesign of the SSME Hot Gas Manifold
- Coupled aero-optics-acoustics analysis of a space observation system, SOFIA

Non-aerospace: Examples of technology reapplications

- First simulation of Artificial Heart (Penn State)
- Development of the NASA/DeBakey Ventricular Assist Device
- Simulation of naval vehicles (submarine and propeller with the navy)



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Future Directions

- RESEARCH

Algorithm :	Convergence Acceleration
	Viscous Separated / Unsteady Flow Methods
	Solution Adaptive Method
	Parallel Computing and Real-Time CFD
	High-speed and chemically reacting flow
Flow Physics:	LES/DNS (Leveraged by CTR's Advances)
	Transition
	Turbulence
	Combustion/ Real gas effects
	Aeroacoustics
IT :	Computational Tool for Non-experts (User-Friendly)
Software :	Outsource (Commercial Vendors)



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